

Impulse and Momentum

What You Need To Know:

The Physics There are many concepts in physics that are defined purely by an equation and not by a description. In some cases, this is a source of much frustration for students since the math doesn't hold much meaning for them. In this lab, we will be dealing with two such cases where students have a particularly difficult time giving meaning to the math.

Impulse In sports, one of the major actions is to hit an object. For example, in baseball, a player will hit a ball with a bat. To be more technical - over a period of time, a baseball player will apply an average force to a ball. In physics, it is said that the player is applying an *impulse* to the ball. Impulse is defined by the following equation ...

$$I = F_{ave} \Delta t$$

I is the impulse (in Newton-seconds, N·s)
 F_{ave} is the average force (in Newtons, N)
 Δt is the change in time (in seconds, s)

Momentum When hitting the baseball, the main objective is to have the ball change direction and move away from the player (preferably at a high speed). In other words, you want the ball to have a change in velocity. So, impulse must have some relationship to a change in the ball's velocity since, in order to make the ball change its velocity, you have to hit it (i.e. apply a force). Impulse does have a relationship but it is related to the ball's *momentum* which is based on the ball's velocity. Momentum is defined by the following equation ...

$$p = mv$$

p is the momentum (in kilogram-meters per second, kg·m/s)
 m is the mass (in kilograms, kg)
 v is the velocity (in meters per second, m/s)

Impulse then can also be defined by the following equation ...

$$I = \Delta p$$

I is the impulse (in N·s)
 Δp is the change in momentum (in kg·m/s)

So combining the two ideas together, we can say that applying a force to an object should give it a change in velocity through the ideas of impulse, momentum, and velocity ... $F_{ave} \Delta t = m \Delta v$.

Momentum for a System In the paragraphs above we were dealing with the momentum for a single object. Now we are going to deal with the *total* momentum for a *system* of objects.

You have already seen that when dealing with *energy* for a system of objects, the *energy* is conserved only on the condition that there are no *non-conservative forces* (like friction) acting in your system. When dealing with *conservation of momentum*, there is also a condition that must be met; there must be no *external forces* acting on your system.

So what's an external force? Let's say we have two balls moving towards each other which then collide. We are going to define **both** balls as our "system". At the moment of impact, there are two forces acting in our system. **See Figure 1.** Ball #1 hits ball #2 with a force to the right and ball #2 hits ball #1 with a force to the left. These two forces compose an action-reaction pair. Remember Newton's 3rd law? ... Equal and opposite forces acting on different objects. If **both** forces in the pair are acting on objects in your **defined system** then they are considered to be *internal* forces. If only **one** force from the action-reaction pair is acting in your **defined system**, then the force is considered to be *external*. This idea will come up later in the lab.

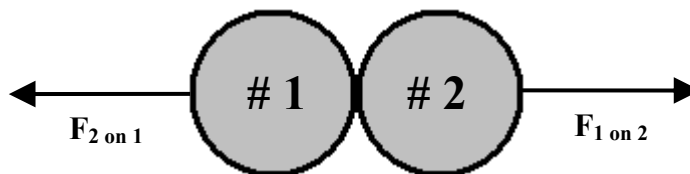


FIGURE 1 - Two balls colliding with action-reaction pair

Conservation of Momentum So, if there are no external forces acting on your defined system then we can say the total momentum for the system will be conserved. Most of the time you'll apply this idea to collisions between two objects. The total momentum of all of your objects before your collision will equal the total momentum of all your objects after your collision. We write this out like the equation below ...

$$\Sigma p = \Sigma p'$$

Σp is the sum of momentum *before* the collision
 $\Sigma p'$ is the sum of momentum *after* the collision

There are three different types of collisions; *elastic*, *inelastic*, and *perfectly inelastic*. In all three types, the momentum is conserved; however, the kinetic energy is not. In an *elastic* collision, the total kinetic energy of all the objects is *conserved* from before the collision to after. An example of this would be a collision between two balls from a pool table. Since the pool balls are very smooth, there is very little energy loss due to friction. Also, when the balls collide, they don't permanently deform (which also requires energy).

In an *inelastic* collision, the kinetic energy is not conserved. This is because, during the collision, there is a loss of energy due to permanent deformation of the objects and friction. An example of this would be a car accident. When the cars collide, the metal of the car is usually bent. It takes quite a bit of energy to do this and that energy is taken from the kinetic energy of the cars. A *perfectly inelastic* collision is basically the same idea as an *inelastic* collision, except the objects stick together.

The Equipment For this lab you will be using carts with signal bouncers, a track, a motion sensor, and a force probe. **See Figure 2.** You will be pushing the carts on the tracks to give them velocities. Please do not allow them to slam into the stop-brackets in front of the motion sensors. Also, in the first part of the lab you will be using a force probe attached to a rubber band. Please use reasonable velocities so the carts do not ricochet violently.

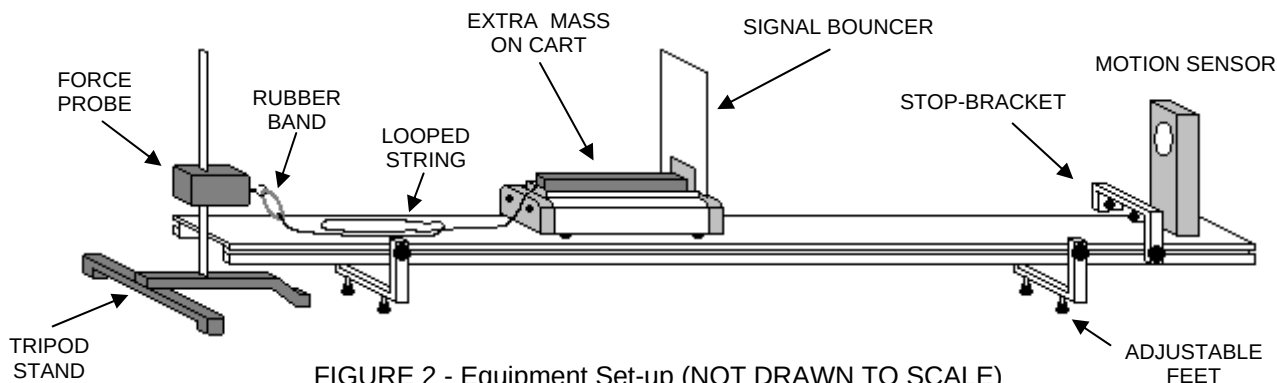


FIGURE 2 - Equipment Set-up (NOT DRAWN TO SCALE)

What You Need To Do:

Part 1 – Impulse In the first part of the lab, you will be examining the relationship between the average force, F_{ave} , acting on an object and the time, Δt , over which it is applied. Remember, when you multiply these values together, you get the impulse delivered to an object. That impulse is also related to the velocity of an object.

The Setup The very first thing you should do is make sure your track is level. You can do this by placing a cart on the track and then letting it go. If it moves, then the track is not level. You can adjust the level of the track by adjusting the feet on the track legs. **See Figure 2.**

Next, you will need to set up your equipment. You will need ...

- Cart #1 with an extra mass and a signal bouncer
- One motion sensor (the one attached to the blue LabPro in port DIG/SONIC1)
- A string with rubber bands attached to one end and a paperclip on the other
- A force probe attached to a tripod stand

NOTE: Make sure the motion sensor is aligned so that it is aimed EXACTLY down the length of the track. If it is aimed at even a slight angle you will get graphs that are jumpy or don't register any motion. If this is ever the case during this lab then check on the alignment of your sensors.

Place a black bar mass on your cart. **See Figure 2.** Make sure it rests in the cart bay so that it is secure otherwise it'll slide off the cart during the experiment. Using the digital scales measure the total mass of the cart, the signal bouncer, and the extra mass. Record this value.

Place the tripod stand at one end of the track so that the vertical rod of the stand is **touching** the end of the track. **See Figure 2.** Position a stop-bracket at the other end of the track, about 20 cm from the end. Put the motion sensor right behind the stop-bracket. Now, attach the paperclip into the *SMALLER* hole in the end of the cart, on the opposite side of the signal bouncer. Attach the *THINNER* rubber band to the eyehook on the force probe. *Do not attach both rubber bands at the same time.*

On your computer, open the file **IMPULSE**. Click CONNECT on the Sensor Confirmation window. The top portion of the screen is a *position vs. time* graph for the cart. The lower portion of the screen is a *force vs. time* graph due to the force on the cart from the rubber band.

Push the ZERO button (next to the green COLLECT button). A smaller window will open. Have only the Dual Range Force item checked and then click OK. NOTE: On the force probe, make sure the ± 10 N is selected.

Make a chart like the one below in your lab report. You are now ready to begin.

Rubber Band	Initial Velocity	Final Velocity	Average Force	Change in Time	Impulse by $m\Delta v$	Impulse by $F\Delta t$	% Diff
THIN							
THICK							

Thin Rubber Band Position the cart so that it is roughly 30 cm away from the force probe. Make sure that the string is looped and placed on the track. **See Figure 2.** This will ensure that, when the cart moves, the string will not get caught on anything. Push COLLECT on the computer screen. Give the cart a push towards the motion sensor. The cart will move out and then get pulled back because of the rubber band. NOTE: You will need to move the string out of the way after it ricochets otherwise the wheels will get caught up on the string and slow the cart down.

Write in your chart that your first trial was done using the thin rubber band. Now you need to collect data from the computer. In the force graph, there will be a red “hill” that represents the changing force of the rubber band on the cart. First, do a sketch of the hill in your lab report. Next, highlight the region from just where the force begins to increase to just after it becomes zero again. Then click on the “STAT” button. This will create a little window that will tell you the mean value of the force (among other things which you can ignore). Record this in your chart under Average Force.

Next, you need to record the change in time, Δt , during the stretching of the rubber band. In the lower left hand corner of the force graph there is a set of parentheses with a Δt in it. The number to the right of this is your change in time value. Record this in your chart.

Now you are going to find the initial velocity of the cart before the rubber band acts on it. *In the position graph on top*, there is a gray region that matches the region you

highlighted in the force graph. Go to the left edge of this region and click and hold the mouse. Slide the mouse to the **left** until the " Δt " value in the lower left of the graph is roughly 0.250, then unclick. Now push the "R=" button; this will open a window which will give you the slope of the line in that region. (What does the slope of a position vs. time graph give you?) Record this value in the chart in the Initial Velocity column. Make sure you include the sign.

If your initial velocity was not between -0.75 m/s and -0.95 m/s, then continue to do the above procedure until you achieve a value in that range with nice smooth lines in your graphs.

Now, you are going to get the final velocity of the cart after the rubber band acts on it. The gray area from the force graph will now be gone so re-highlight the force graph. In the position graph on top go to the right edge of the gray region and click and hold the mouse. Drag it to the **right** until $\Delta t = 0.250$. Push "R=" again and record your final velocity value in your chart.

You will be measuring a lot of velocities this way during this lab, so if you aren't clear on what you are doing then grab your TA and ask him/her to help you.

Using the data you have collected, calculate the impulse in the two different ways discussed in the introduction of this lab. Show sample calculations below your chart. Put these values in the chart. Calculate a percent difference using these two values and place that in the chart. If you got a percent difference more than 8%, you are probably doing something wrong. Figure out your problem before you move on to the next part.

Do your calculations with these acceptable values and then proceed.

Question 1 Was the cart's momentum conserved from before the cart ricocheted to after? How can you tell? HINT: Momentum is a *vector* value.

Question 2 Explain why the momentum was or was not conserved based on what was discussed in the intro to the lab.

Thick Rubber Band Remove the thin rubber band from the eyehook and attach the thick rubber band. Repeat the above procedure. Again, make sure your initial velocity is between -0.75 m/s and -0.95 m/s. (It would be even better if you can match the initial velocity from the thin rubber band trial!) NOTE: It is okay if the red force line goes outside the range of the visible graph area. When you have achieved appropriate values and decent looking graphs, then record your data. Do your calculations and also make a sketch of the force graph next to the one you did for the thin rubber band.

Question 3 Examine the force graphs that you drew for each rubber band. Assuming that the initial velocities of the cart for both rubber bands are the same, what can you say about the relationship between the force applied to the cart and the time, Δt , it was applied? (In answering this question, it may be helpful to compare the impulse values you calculated for the thin and thick bands.)

Question 4 Keeping your answer to Question 3 in mind ... In a car collision, the driver's body must change speed from a high value to zero. This is true whether or not an airbag is used, so why use an air bag? How does this reduce injury?

Part 2 – Conservation of Momentum In the first part of the lab, you examined the velocity and momentum for a single object. Now you are going to examine the total momentum of TWO objects before and after a collision.

The Setup You will need the following equipment ...

- Two carts each with a signal bouncer
- Two motion sensors and two stop-brackets
- An extra mass
- A piece of clay with a piece of cellophane

Put the two stop-brackets on opposite ends of the track, about 10 cm from the ends. One is already attached to the track. The other is on your table. Attach it by sliding the nut (with the screw threaded already) into the slot that runs the length of the edge of the track. Once positioned, tighten it into place.

Remove the paperclip/string from the cart. Do not untie the string on either end.

Students closest to the windows: Take your motion sensor from port DIG/SONIC1 and plug it into DIG/SONIC2. Plug in the other motion sensor into the port DIG/SONIC1 and place it on the left end of the track behind the stop-brackets.

Students farthest from the windows: Take your other motion sensor and plug it into the port DIG/SONIC2 and place it on the right end of the track behind the stop-brackets.

Make a chart like the one below in your lab report. Make at least 6 or more rows to encompass the rest of the lab.

	Cart #1			Cart #2			Total Momentum		Kinetic Energy		
Trial	Mass	Initial Velocity	Final Velocity	Mass	Initial Velocity	Final Velocity	Before	After	Before	After	KE loss
Elastic											
Inelastic											
Perfectly Inelastic											

You will be using both carts now either with or without the extra mass. Use the digital scales to find the mass of the cart and bouncer without the extra mass. For the first trial you will be using the carts without the extra mass so write down the appropriate masses for both carts in your chart for Trial #1.

Now, place both carts on the track so the “M’s” on the sides of the carts are facing each other. Cart #1 should be on the left and Cart #2 on the right. Also, at this stage both signal bouncers should be on the side of the cart **WITHOUT** the “M’s”. If this is not the case then get the Philips screwdriver at the front of the lab and move the signal bouncer to the other side. **NOTE:** Put the signal bouncer in place **BEFORE** you tighten the screw.

Move Cart #1 so it’s about 50 cm from the left motion sensor. Place Cart #2 so its left side is at 120 cm on the track. Consider this the Starting Position.

Elastic Collision – Same Mass The carts are now set up for an elastic collision. Both carts should now have the same mass. You do not need the computer for this part. Give Cart #1 a little push and let it collide with Cart #2 which is at rest. **Please** keep in mind that this is not NASCAR.

Question 5 Based on what you observed, what happened to the momentum from Cart #1? Why do you think the collision occurred the way it did?

Question 6 What do you think will happen if Cart #2 had the extra mass in it when they collide? Explain why you think this.

On your computer, open the file named **MOMENTUM**. Both graphs are position vs. time graphs. The top graph is for Cart #1 and the bottom graph is for Cart #2.

Return both carts to Starting Position. Push **COLLECT** on the computer. Give Cart #1 a push and let it collide with Cart #2 at rest. You should see on the screen graphs that look similar to the ones in **Figure 3**. If not, then try another run or grab your TA.

Now you are going to measure both carts’ velocities before and after the collisions using your graphs. Do this in the same way you did in the first part of the lab. Make sure you highlight your regions *just before* and *just after* the collision. See **Figure 3**. As before, make sure the width of the region is about 0.250 seconds.

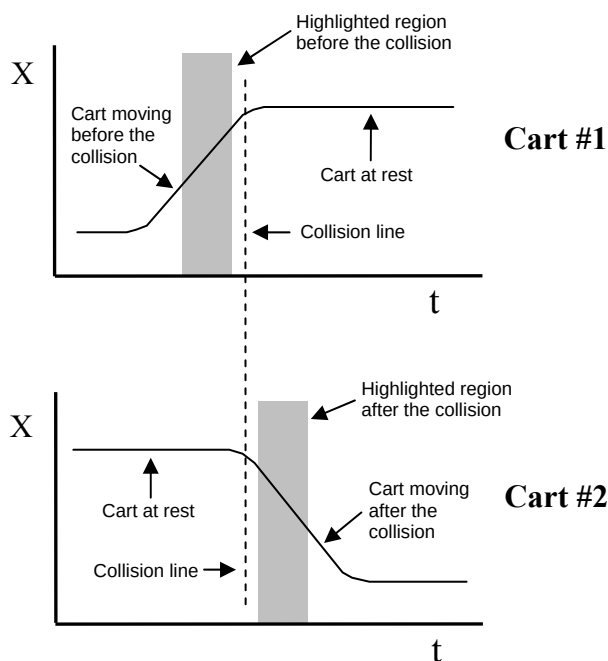


FIGURE 3 – Position vs. Time Graphs

NOTE: Since the motion sensors are facing opposite directions, their directional signs do not agree, therefore, *you* choose a direction that you will call positive and assign negative velocity values so that they agree with your choice.

Try to get an initial velocity for Cart #1 to be in between 0.4 m/s and 0.5 m/s. Keep doing trial runs until you are good at getting smooth graphs and a velocity in the given range. When you have a good run then record the values in your chart.

$$p = mv$$

$$KE = \frac{1}{2}mv^2$$

Calculate the total momentum before and after the collision. (Equations are off to the left.) For example ...

$$p_{\text{total, before}} = p_{\text{cart \#1, before}} + p_{\text{cart \#2, before}}$$

Put the values in the chart. Also calculate the total kinetic energy before and after in the same way. Calculate the kinetic energy loss too. Place all of these values in the chart.

Question 7 Was the momentum conserved for your *system* from before to after? Explain why in terms of what was discussed in the intro.

Question 8 Was the momentum conserved for *Cart #1* from before to after? Explain why in terms of what was discussed in the intro.

Question 9 Physically speaking, why is this collision considered to be elastic? Do your calculated values for the kinetic energies reflect this? Explain.

Elastic Collision – Different Mass Place the extra mass on Cart #2. Return both carts to Starting Position. You do not have to take data for this run. Give Cart #1 a push and let the carts collide.

Question 10 Referring back to **Question 6**, was your prediction correct? If not, explain why.

Question 11 What do you think will happen if Cart #2 is moving first and Cart #1 is at rest? Try it. What do you conclude?

Inelastic Collision – Different Mass Remove the extra mass from Cart #2. Take the cart and go to the front of the lab room and use the screwdriver to remove the top L-plate and switch the signal bouncer to the other side, i.e. the side *with* the “M”.

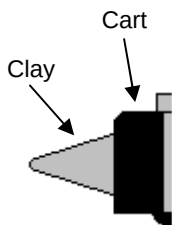


FIGURE 4

Now, take the clay and form it into a circular cone about an inch and a half long. Stick it to the side of Cart #2, opposite the signal bouncer. **See Figure 4.** Also, cover the tip of the cone with the piece of cellophane. **NOTE:** Each time you have the carts collide you have to reform the clay into a cone before doing another run.

Return the extra mass to Cart #2 and place the carts at Starting Position. Give Cart #1 a push and let it collide with Cart #2 at rest. Take data on a run in which Cart #1's initial velocity is between 0.6 m/s and 0.7 m/s. Make sure you have smooth graphs. Do your calculations.

Question 12 Was the total momentum conserved for this collision? Is this consistent with what you read in the intro? Explain.

Question 13 Physically speaking, why is this collision considered to be inelastic? Do your calculated values for the kinetic energies reflect this?

Perfectly Inelastic Collision – Different Mass Remove the clay from Cart #2 but keep the extra mass. The Velcro™ on the sides of the carts will make them stick together when they collide. Give Cart #1 a push and let it collide with Cart #2 at rest. Take data on one run in which Cart #1's initial velocity is between 0.6 m/s and 0.7 m/s. Do your calculations.

Question 14 Was the total momentum conserved for this collision? Is this consistent with what you read in the intro? Explain.

Question 15 Look at the KE losses for your inelastic collision as compared to your perfectly inelastic collision. Why do you think that there are higher losses for the inelastic case?

What You Need To Turn In:

Questions and Calculations Along with your data, make sure that you include one sample calculation for each different equation for each type of collision. Also make sure you have answered all of the questions.